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# MULTIPOINT MEASUREMENTS FROM SUBSTORM ONSET TO RECOVERY: THE RELATION BETWEEN MAGNETIC PULSATIONS AND PLASMA SHEET THICKENING

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## ABSTRACT

Long duration waves in the Pi 2 frequency band (6.7 - 22 mHz) were observed by the Air Force Geophysics Laboratory (AFGL) Magnetometer Network during a set of substorms previously analyzed by Hones et al. /1/. For these events, Hones et al. found that on the order of 1 hour after the expansive phase onset of a substorm, there was a sudden appearance of riometer absorption observed at South Pole Station (magnetic latitude about -75°) and a reappearance of the plasma sheet as observed in 6-keV electrons by ISEE 1 and 2 satellites at a distance of 15 to 20  $R_E$  in the magnetotail. The wave activity observed at the AFGL stations during these events diminished significantly at approximately the time of the plasma sheet recovery or riometer increase. One explanation for the long duration of these waves is that following substorm onset they are continuously generated in a near-tail reconnection region and then decay when the neutral line moves tailward during the substorm recovery phase.

## INTRODUCTION

A considerable wealth of data exists regarding the expansive phase onset of substorms, but comparatively little is known about the later recovery phase /2/. In this paper, we examine ground-based observations of magnetic pulsations in the Pi 2 band (periods 40-150 s) /3/ that continue into the late stage of substorms. These observations are compared to other ground-based and spacecraft observations with the intention of learning more about the late phase of substorms and the substorm process.

Pi 2's are often used as signatures of the expansive phase onset of magnetospheric substorms and there have been numerous studies regarding the properties of the initial few cycles of these waves. The waves typically decay after a few to ten minutes /4/; however, in this paper we study enhanced wave activity of longer duration that was observed by the Air Force Geophysics Laboratory (AFGL) Magnetometer Network in a set of substorms analyzed by Hones et al. /1/.

The principal data sets used in this study are from the AFGL Magnetometer Network which spans the United States at about 55° magnetic latitude, the University of Maryland 30 MHz riometer operated at the South Pole, and ISEE satellite measurements of 6-keV electrons from energetic particle detectors designed at the University of California, Berkeley, and Centre d'Etudes Spatiales de Rayonnement (CESR), Toulouse. Details are given in the Hones et al. paper /1/.

### Background and Event Overview

One of the eight events discussed in detail in the paper by Hones et al. /1/ is shown in Figure 1. This event on 13 Apr 1983 can be used to summarize the Hones et al. results as well as to set the framework for the pulsation observations shown in this paper. The solid curve is the geomagnetic X component from Great Whale River which is near local magnetic midnight at 0600 UT. A magnetic bay begins at about 0425 UT, and a very sharp decrease in the X component is observed a few minutes later. Pi 2 pulsations, with their beginning designated by a solid circle, were observed at the AFGL stations at about this same time or slightly earlier at 0420 UT (see Figure 2). The dotted curve shows the South Pole 30 MHz riometer absorption and the dashed curve shows the ISEE 6-keV electron flux. Both of these curves show a strong increase at about 0532 UT. At the time of the electron flux increase ISEE is located about 16.8  $R_E$  down the tail (GSM coordinates are: X = -16.8  $R_E$ , Y = 4.0  $R_E$ , Z = -5.5  $R_E$ ).

The important point in Figure 1 is that a substorm expansion phase onset occurs, as indicated by the Pi 2 and magnetic bay about 0420-0425 UT. These signatures of substorm expansion onset precede by about 1 hour the detection of precipitation at high latitudes (riometer increase) and plasma sheet expansion (electron flux increase). Hones et al. interpreted this and a set of similar observations to suggest that reconnection at a near-earth neutral line begins at the substorm expansion onset (Pi 2 and bay), and after continuing for about an hour is followed by a tailward retreat of the reconnection region indicated by the plasma sheet expansion and appearance of precipitation at higher latitudes (riometer increase at South Pole).

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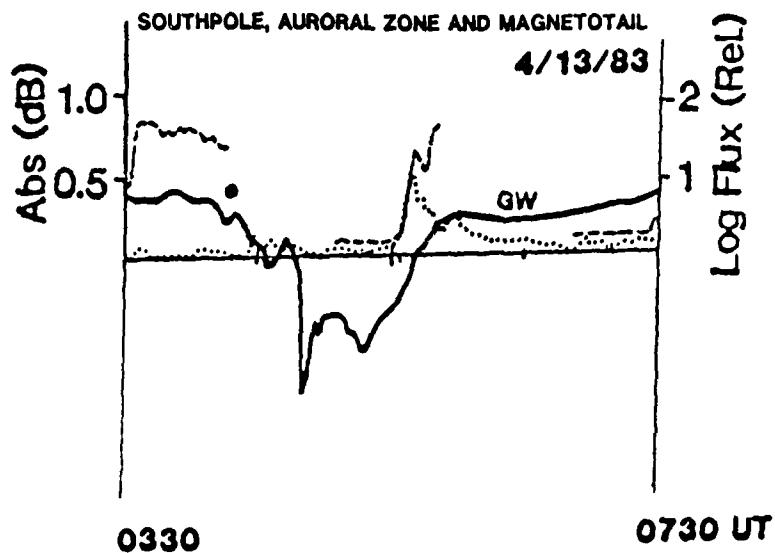


Fig. 1. South Pole riometer absorption (dotted line) and ISEE 6 keV electrons (dashed line) showing an increase about 0532 UT following a substorm expansion onset indicated by AFGL Pi 2 pulsations (solid dot) and a negative X bay at Great Whale River (GW-solid line). From Hones et al. /1/.

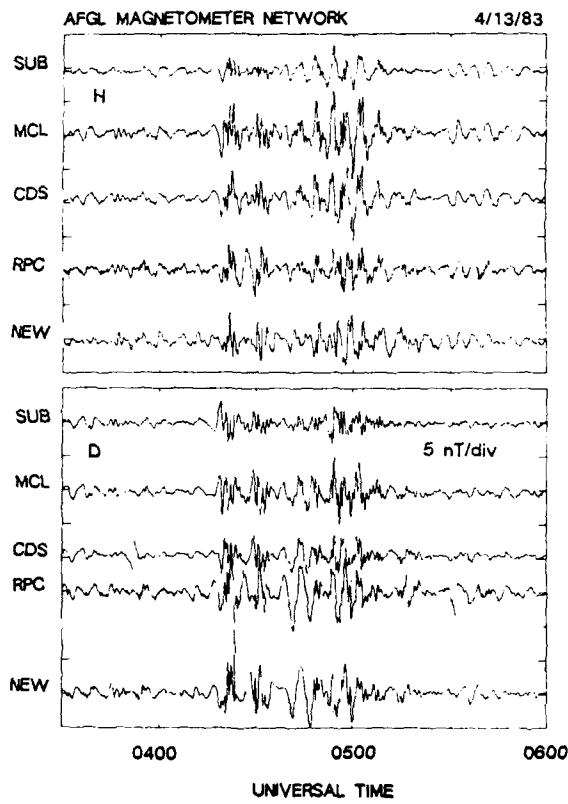


Fig. 2. H and D component high pass filtered (5 min cutoff) wave data from the 5 northern AFGL stations.

#### OBSERVATIONS

Figure 2 shows the H and D components (magnetic north and magnetic east) of 5-sec averages of the magnetic field data from the 5 northern stations of the AFGL Magnetometer Network during the first portion of the interval (0330-0600 UT) on 13 Apr 1983 shown in the previous figure.

The data have been high-pass filtered with a cutoff at about 5 minute period and the scale is 5 nT/div. At 0420 UT, near the time of the substorm onset the stations span the region from about 2000 MLT to midnight local time. Pi 2 type wave activity is enhanced for about a one-hour interval beginning about 0420 UT. The plasma sheet recovery at ISEE was observed at 0532 UT, just after the decay of this wave activity. Frequency changes and phase jumps observed in the waves suggest that they result from more complicated activity than a single impulse that is subsequently damped.

Details of the frequency and amplitude structure in the enhanced wave activity were examined by producing dynamic spectra (not shown) of the sum of the power spectra of the horizontal components of the magnetic field data for each of the eight Hones et al. events. However, to better quantify the results, for each event the power in the Pi 2 frequency band (including wave periods from about 40-150 s) was integrated in 5 minute windows throughout the event. Using these data, we selected the one station from the network that best observed the substorm expansion onset (except for two cases where a nearby station was used because of improved data quality) by choosing the station that observed the largest integrated power in the Pi 2 band during the interval. The results of this analysis for 13 Apr 1983 are shown in Figure 3. There is a large increase in power at the substorm expansion phase onset that continues for much longer than typical Pi 2 pulsations [4], and a decrease to low levels near the time of the plasma sheet recovery. (Just after 0630 UT there is another smaller enhancement of wave power that is probably associated with a new, weaker substorm onset.)

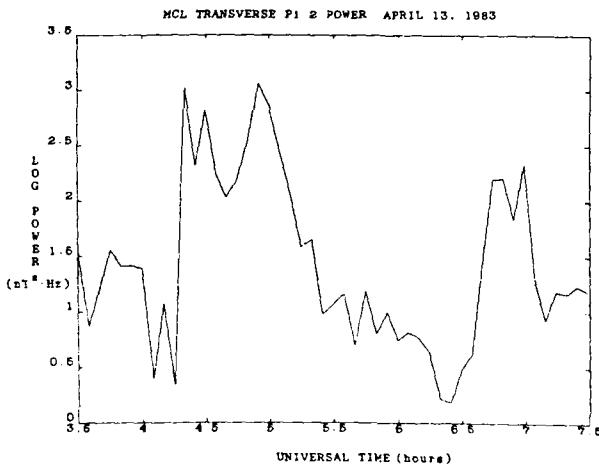


Fig. 3. Total horizontal wave power integrated in the Pi 2 pulsation band from the AFGL station Mount Clemens, Michigan.

Similar results were found for the other events. Figure 4 shows the integrated power in the Pi 2 band on a linear scale normalized to the peak power for each event. Eight hours of data are shown centered on time = 0 which indicates the time of the plasma sheet recovery in the tail for each of the events. Although this type of display conveniently summarizes all the events, it can also be misleading. Therefore, we have used four different line types (solid, dot, dash and dash-dot) to indicate that the variability observed is due to more than one or two of the events. For each event there is substantial wave activity associated with multiple substorm onsets sometime during the four hours preceding the plasma sheet recovery, but very little activity (the power diminishes by nearly an order of magnitude) during at least 3 hours following the recovery. Later, as one might expect from substorm occurrence time scales, new substorm activity appears.

#### DISCUSSION

Our observations can be placed in the context of the near-earth neutral line substorm model [5]. At the substorm expansion phase onset (step 2 in the Hones model [5]), stretched out, tail-like field lines collapse and become more dipolar in the inner magnetosphere. Alfvén waves are generated by this reconfiguration, and during the reconnection process as there are transient changes in the field-aligned current systems.

Although typical Pi 2 pulsations have periods of about 100 s and their amplitude decays substantially after about 4 wave cycles or about 7 minutes [4], the waves for the events studied here are of much longer duration. Therefore, we suggest that while near-tail reconnection continues (at varying rates), Alfvén waves are continuously generated and the wave activity ceases when reconnection ceases or weakens, or as the neutral line moves down the tail (step 9 to 10 in [5]). There are several possible explanations for the decay of the wave amplitude to background levels. The wave amplitude can diminish because reconnection weakens, or the reconnection region moves down the tail and becomes coupled to higher latitude field lines which are now more remote from the mid-latitude stations. Furthermore, if the region is farther down the tail, the waves may be attenuated more in traveling the greater distance.

The relationship among the substorm features discussed in this paper (long duration Pi 2's,

plasma sheet expansion and riometer increase) may be related in part to the location of the observations and the level of geomagnetic activity. The events in this study all occurred during intervals of moderate to high  $K_p$  (4' to 6'), although they were not selected in that way. During high  $K_p$  an expanded polar cap means that the auroral breakup regions should map closer to the earth than for substorms during lower  $K_p$  intervals. Therefore, it is more likely for these events that the near-Earth neutral line is inside of the ISEE orbit than for substorms during low  $K_p$ .

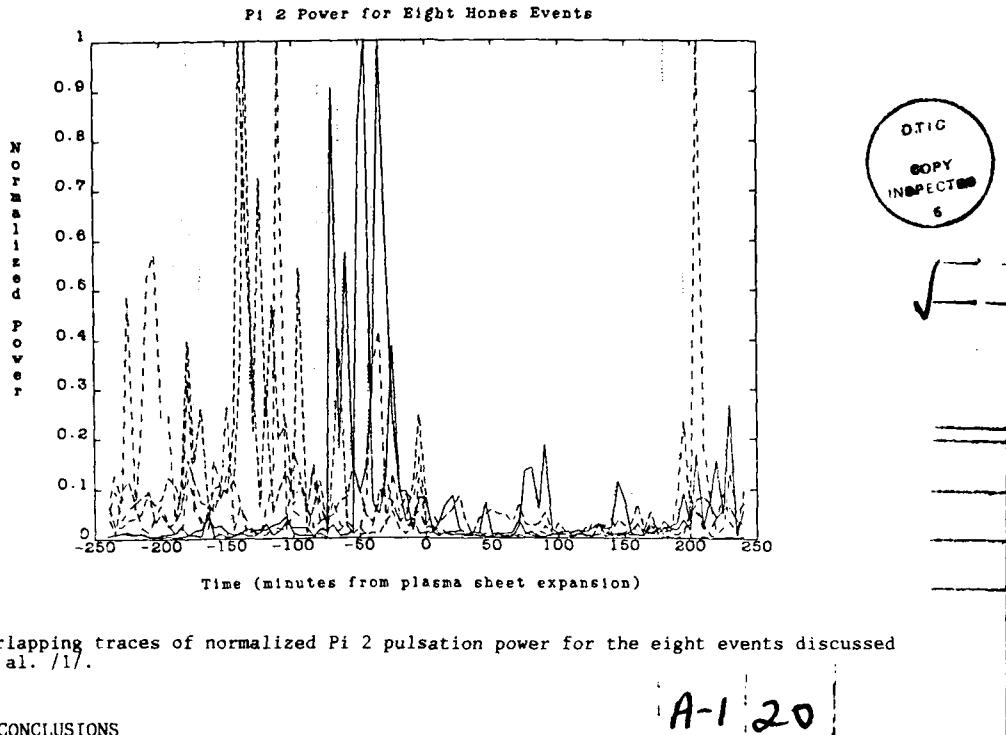


Fig. 4. Overlapping traces of normalized Pi 2 pulsation power for the eight events discussed by Hones *et al.* /17.

#### CONCLUSIONS

We have shown that for substorms during high levels of geomagnetic activity, long duration pulsations in the Pi 2 band are observed at mid-latitude magnetic observatories. The pulsations are not simply damped waves following an initial impulse, rather they are continuously generated. They decay near the time of the recovery of the plasma sheet in the magnetotail, suggesting that they are signatures of the reconnection process, and continue as long as a near-earth neutral line exists. When reconnection at the neutral line diminishes in strength or the neutral line retreats tailward, the waves also diminish. These long duration Pi 2 pulsations convey information about their source, and further study may provide us with new insights regarding the reconnection process in the earth's magnetotail.

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